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THE EFFECT OF THE ADDITION OF ACTIVE DIGESTER EFFLUENT FOR START-UP ACCELERATOR IN ANAEROBIC DIGESTION OF SOYBEAN CURD INDUSTRY WASTE WATER (BASIC RESEARCH FOR BIOGAS POWER GENERATION)

PENGARUH PENAMBAHAN EFFLUENT DIGESTER AKTIF UNTUK MEMPERCEPAT START-UP PERURAIAN ANAEROBIK AIR LIMBAH INDUSTRI TAHU (RISET DASAR PEMBANGKIT LISTRIK TENAGA BIOGAS)

Arini Wresta [a, b, *], Wiratni Budhijanto [a]

[a] Laboratory of Food and Bioprocess Engineering, Chemical Engineering Department
Faculty of Engineering, Gadjah Mada University, Jl. Grafika 2, Yogyakarta 55281 Indonesia
[b] Research Centre for Electrical Power and Mechatronics-Indonesian Institute of Sciences,
Jl. Cisitu No. 21/154 D, Bandung 40135 Indonesia

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Abstract

Biogas production from soybean curd industry waste water was studied in laboratory scale to improve the application of anaerobic digestion process. The problem with the soybean curd waste water was the fact that it does not sufficiently contain anaerobic microorganisms required in biogas production. Therefore, it is necessary to add a well-developed population of anaerobic microorganisms to accelerate the start-up of the anerobic digestion. This research was aimed to verify the influence of the addition of active digester effluent into the soybean curd waste water batches in an anaerobic digestion process. Batch experiments were done in two digesters. The first digester was only fed with soybean curd waste water while the second digester was fed with soybean curd waste water and active digester effluent from a digester processing cow manure which was very rich in anaerobic microorganism consortium. The results indicated that soybean curd industry waste water did not contain methanogenic bacteria but there existed some acidogenic bacteria. The addition of active digester effluent accelerated the anaerobic digestion start-up and directed the process pathway towards methanogenic process so that more methane was obtained. The high methane content obtained (more than 64% volume) was very potential for power generation. The capacity of soybean curd industry must be as high as 697.13 kg soybean per day to generate the electric energy of 8.4 kWh.

Key words: active digester effluent, start-up, anaerobic digestion, soybean curd waste water, anaerobic bacteria, methanogenic process, electric energy.

Abstrak

Untuk memperluas aplikasi proses peruraian anaerobik, telah dilakukan proses pembuatan biogas skala laboratorium dengan substrat air limbah industri tahu. Masalah yang dihadapi adalah sedikitnya bakteri-bakteri anaerobik di dalam air limbah tersebut. Oleh karena itu, untuk mempercepat start-up pembuatan biogas diperlukan starter yang banyak mengandung bakteri-bakteri anaerobik. Penelitian ini bertujuan untuk menguji pengaruh penambahan effluent digester aktif sebagai starter pada peruraian anaerobik air limbah tahu. Penelitian dilakukan dalam dua buah digester batch berisi 600 gram bahan baku, dimana digester pertama berisi air limbah tahu saja dan digester ke-2 berisi air limbah tahu dan starter effluent digester kotoran sapi aktif yang sangat kaya akan konsorsium bakteri-bakteri anaerobik. Hasil percobaan menunjukkan bahwa air limbah tahu mengandung bakteri asidogen tetapi tidak mengandung bakteri metanogen. Penambahan effluent digester aktif sebagai starter mempercepat star-up peruraian anaerobik dan mengarahkan jalannya proses ke metanogenesis sehingga diperoleh produk akhir berupa metana. Kadar metana yang dihasilkan mencapai di atas 64% sehingga sangat potensial untuk pembangkit listrik. Energi listrik sebesar 8,4 kWh dapat dibangkitkan dari industri tahu dengan kapasitas 697,13 kg kedelai per hari.

Kata kunci: effluent digester aktif, start-up, peruraian anaerobik, air limbah tahu, bakteri anaerobik, metanogenesis, energi listrik.

* Corresponding Author. Tel: +62-22-2503055
E-mail: awresta@gmail.com

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I. INTRODUCTION

As a country that rich of organic resources also known as biomass, Indonesia has started to encourage biogas technology as an alternative renewable energy. The simple process, environmently friendly maintenance, and low cost investment are the strength of this bio fuel. In the long run, when the fossil fuel crude oil and natural gas is not available anymore, biogas will be one of the crucial energy source in the world.

Puslit Telimek LIPI has applied cow manure biogas production for electricity since 2008 until now by IPTEKDA Program (2008, 2010, 2011), PKPP DIKTI Program (2009), Ristek Speklok Program (2011), and PKPP Ristek Program (2012). The advantage of cow manure as the anaerobic digestion feed is its content of anaerobic bacteria that will trigger the process to run well without the addition of any starters. However, the data taken from biogas digester installation in Pesantren Saung Balong Al Barokah Majalengka indicated that the anaerobic digestion process of the cow manure was not satisfying because just little power can be generated caused by the little gas produced from the digester [1]. This field finding implied that even for cow manure, additional starter might be necessary to quickly recover the digester from the problem.

The laboratory research of biogas formation from the waste water of soybean curd industry was done in Laboratory of Food and Bioprocess Engineering, Chemical Engineering, Gadjah Mada University, as the first author's thesis. The final goal of this research was to develop the expand of biogas production application possibility for electricity in Puslit Telimek LIPI with anothers sources of substrate. This paper specifically reports the effect of active digester effluent as a starter in soybean curd waste water for biogas production. This research will also estimate the amount of soybean curd industry waste water needed to generate a certain amount of electric power. The other parameters that affect the utilization of soybean curd waste water as anaerobic digestion substrate will be discussed in another publication.

II. FUNDAMENTAL

A. Biogas Formation and the Bacteria Involved

Biogas formation is a microbiology process that involves a consortium of anaerobic bacteria. This process utilizes anaerobic bacteria metabolism activity to get the energy needed for their live. For this need, the bacteria degrade organic compounds and take the energy released from the process. The side products are simple compounds and biogas, mainly contain of CH_4 and CO_2. The methane content in the biogas can achieve 70% volume of all gas produced [2]. This gas exhibits high energy value and can be used as fuel. Biogas production process has been used since long time ago to get the alternative energy that can substitute crude oil and natural gas.

Biogas production process consist of hydrolysis, acidogenic, and methanogenic steps [3]. Hydrolysis is the degradation of unsoluble complex organic compounds by anaerobic and facultatively anaerobic bacteria. The products of this step are soluble simple organic compounds. The simple organic compounds then be utilized by acidogenic bacteria to produce short-chain fatty acids. Methanogenic bacteria then use this acids as substrate and convert them into CH_4 and CO_2.

The bacteria involved in hydrolysis and acidogenic steps are obligatorily and facultatively anaerobic bacteria, but the majority are facultative [4]. Facultative anaerobes are active in the presence or absence of free molecular oxygen [5]. The optimal pH and temperature for acidogenic bacteria are T = 35°C and pH = 4-6 [3]. Methanogenic bacteria are strict anaerobes, that will die in the presence of free molecular oxygen [5]. The optimal pH and temperature of methanogenic bacteria are T = 35 to 40°C and pH = 7 to 8 [3]. The methanogenic bacteria is very sensitive with environmental condition change.

In order to get the desired product (CH_4), all of the syntropic bacteria have to be exist in the biogas system. The absence of one group of bacteria involved in one step will cause the process uncomplete and the desired product is not formed.

B. Anaerobic Digestion of Soybean Curd Waste Water and Active Digester Effluent as a Starter

Many researches have been done to utilize industrial waste water containing organic compound as source of substrate for biogas formation. Some of them are Kavacik and Topaloglu (2010) research in co-digestion of cheese whey and dairy manure [6], Ward (2010) research in co-digestion of cow manure and stearin [7], and Damayanti (2010) research in co-digestion of stillage and cow manure [8]. These researches studied co-digestion process in which the waste water was mixed with manure, so that there are anaerobic bacteria involved in biogas formation existed. However, not all industries locations are closed to the animal farms, and for this industries it is needed a method to make the methane formation from the waste run well without the continuous addition of the manure.

One of industrial waste water that is potential to be used as anaerobic digestion substrate is the waste water from soybean curd industry. This waste water is a scrap waste water from protein coagulation in soymilk [9]. The protein and lipid content up to 70% of all organic compound in this waste water [10], so that according to Buswell equation [11], this waste water potentially produce great number of gas with high methane content.

There are five steps in soybean curd formation process, i.e. washing, grinding, cooking, filtration, and coagulation [9]. Soybean curd is obtained after the protein coagulation with the addition of acid, so that the waste water produced have low pH value approximately of 4-5 [12]. The opened soybean curd formation process and the low pH value of the waste water cause the methanogenic bacteria did not grow in this waste. However, the acidogenic bacteria can potentially grow in this waste water because the bacteria are facultatively anaerobic and like to grow in the medium having low pH value.

Due to the low existence of the methanogenic bacteria in the soybean curd waste water, the methanogenic process will not immediately happen in anaerobic digestion of this waste water without the addition of starter containing many methanogenic bacteria. For this purpose, active digester effluent may be used as a starter. There are acidogenic and methanogenic bacteria in this effluent. Sufficiently high amount methanogenic bacteria may exist in this effluent, because this starter is produced from anaerobic digestion process that has successfully produce methane.

C. The Calculation of the Potentiality for Power Generation

Biogas electric power is generated by utilize the energy released from the combustion of methane in the biogas. This energy than be converted to electricity using a device named as Gen-Set. The energy that can be generated is calculated by:

$$E = \eta . n . \Delta Hc \tag{1}$$

where E is the energy potentially generated from biogas Gen-Set (joule), n is the amount of methane obtained from the biogas digester fed with m kg of substrate (mole), and ΔHc is the heat of combustion of methane (802,620 joule/mole [13]). The methane obtained from the biogas digester is calculated by ideal gas law:

$$n = \frac{P'.V}{RT} \tag{2}$$

where P' is pressure (atm), V is methane volume obtained, R is ideal gas constant (0.082 lt.atm/mole.K), and T is temperature (K).

If the power to be generated is P (watt) and the generating time is t (seconds), the energy that must be provided to generate the power (Ed, joule) is:

$$Ed = P \times t \tag{3}$$

The amount of substrate which must be fed in to the digester to generate the power (M, kg) is:

$$M = \left(\frac{Ed}{E}\right) \times m \tag{4}$$

III. EXPERIMENTAL

Soybean curd waste water used in this research was the soybean curd whey from home-scale soybean curd industry in Village of Jetis, Tirtomartani, Kalasan, Sleman, Indonesia. Analysis results showed the total anaerobic bacteria concentration of 4 x 10^6 cells/mL, pH value of 4, volatile solid (VS) concentration of 5.8382 g/L, and volatile fatty acids (VFA) concentration of 509.4897 mg/L as acetic acid.

Active digester effluent used in this research is got from cow manure biogas installation in Kebun Pendidikan, Penelitian, dan Pengembangan Pertanian Universitas Gadjah Mada (KP4 UGM), in Berbah, Sleman, Yogyakarta, Indonesia. Analysis results showed the anaerobic bacteria concentration of 27 x 10^8 cells/mL, pH value of 7, VS concentration of 17.3160 g/L, and VFA concentration of 332.2962 mg/L as acetic acid.

Biogas digester was 1,000 ml Erlenmeyer flask, connected with gas bubbler to detect the gas formed from the digester. Gas bubbler was connected with water manometer to measure the volume of gas formed. The experimental set up is represented in Figure 1.

Batch experiment was conducted in room temperature (ranged between 29-30°C during the experiments). Two digesters were fed with 600 gram raw material. The first digester only contained soybean curd waste water while the second digester contained 400 gram soybean curd waste water and 200 gram cow manure active digester effluent. After all of the material were fed into the digester, nitrogen gas was flushed to remove the air in the digester gas space. Sludge and gas sample was taken weekly for VS and VFA analysis according to standard method [14] and CH_4 analysis using GC (Shimadzu GC 14B, Japan, with FID detector, SUS Packed Column

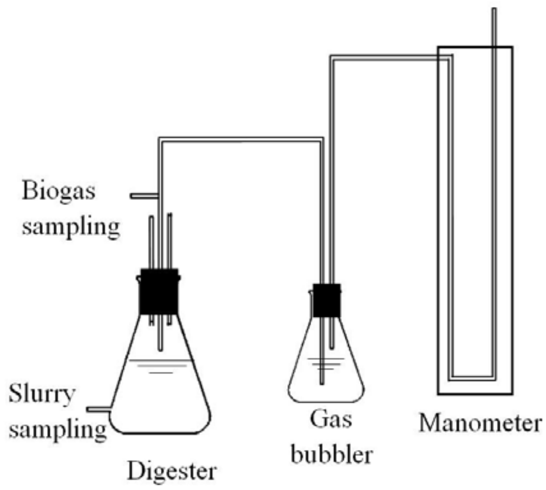

Figure 1. Experimental set up.

Porapak Q, 5m x 3mm I.D., 50°C Column Oven Temperature, and 170 kPa Inlet Pressure). The volume of gas formed was measured every day by recording the water level difference at the manometer legs.

IV. RESULTS AND DISCUSSIONS

A. The Effect of the Addition of Active Digester Effluent

The experimental results are presented in Figure 2. Figure 2a shows the correlation between VS concentration and time. The VS concentration in the digester with the addition of active digester effluent as a starter decreased earlier than in the digester without starter addition indicating the earlier organic compounds degradation and VFA formation by acidogenic bacteria. VFA concentration in the digester with starter addition increased quickly since the initial process (Figure 2b). This phenomena indicated the earlier organic degradation start-up that may happen because the acidogenic bacteria are also existing in the active digester effluent. The acidogenic bacteria in the starter are more well-developed than those in the soybean curd waste water so that the addition of this starter caused a significant effect in the organic compounds degradation rate.

The fast organic compounds degradation in the digester with starter addition implied in the high production of VFA. VFA concentration reached more than 1,500 mg acetic acid/L at day 6. In agreement with Karakhasev, et al. (2005) statement that the dominant bacteria in the sludge digester are *methanosaetaceae* [15], the high VFA concentration in this digester provides enough substrate for *methanosaetaceae* methanogenic bacteria so that the methane cumulative volume produced is high (Figure 2c), as high as more than 450 mL in day 18. The additional methanogenic bacteria from the active digester effluent caused the fast methane formation, but the low soybean curd waste water pH value caused methanogenic bacteria need long time to adaptate. Methane formation start-up began in day 5, which was much faster to be compared with the digester without starter addition that took 20 days for the methanogenic bacteria to kick-off. The methane content in the biogas was sufficiently high, i.e. reached more than 64% volume in day 18 (Figure 2d). The residual protein and lipid in the soybean curd waste water caused the high methane content in the gas produced. This value was higher than if cow manure used as source of substrate as high as 53.0003% [8], so that this biogas has high energy value and very potential for power generation. The high methane content will impact in gen-set efficiency especially in voltage value [16].

The organic compounds degradation in the digester without starter addition is later, caused by the few acidogenic bacteria in the soybean curd waste water (Figure 2a). Anaerobic bacteria concentration in this waste water was $4x10^6$ cells/mL, much lower than the anaerobic bacteria in the active digester effluent about $27x10^8$ cells/mL. However, the differences of organic compounds degradation in the digester with starter addition and in the digester without starter addition can not be seen clearly in Figure 2a caused by the difficulty to analyze the VS concentration accurately, especially in the low concentration. This degradation can be seen more clearly in the trend of VFA concentration. The later organic compound degradation would imply in the later VFA formation. Figure 2b show that the VFA formation in the digester without starter addition did not happen in some initial days, and the VFA concentration start increased quickly in day 12 process. In this start-up time (day 12) the acidogenic bacteria amount may have been high enough as the result from the growth in the time before. The highest VFA concentration was reached in day 28 about 1,391.37 mg acetic acid/L.

The VFA concentration in the digester without starter was not significant different with the VFA concentration in the digester with starter (Figure 2b), but the methane formation didn't happen in this digester until day 33 process (Figure 2c and 2d). The methane content and cumulative volume were still 0 until the end process. This phenomena acknowledge the

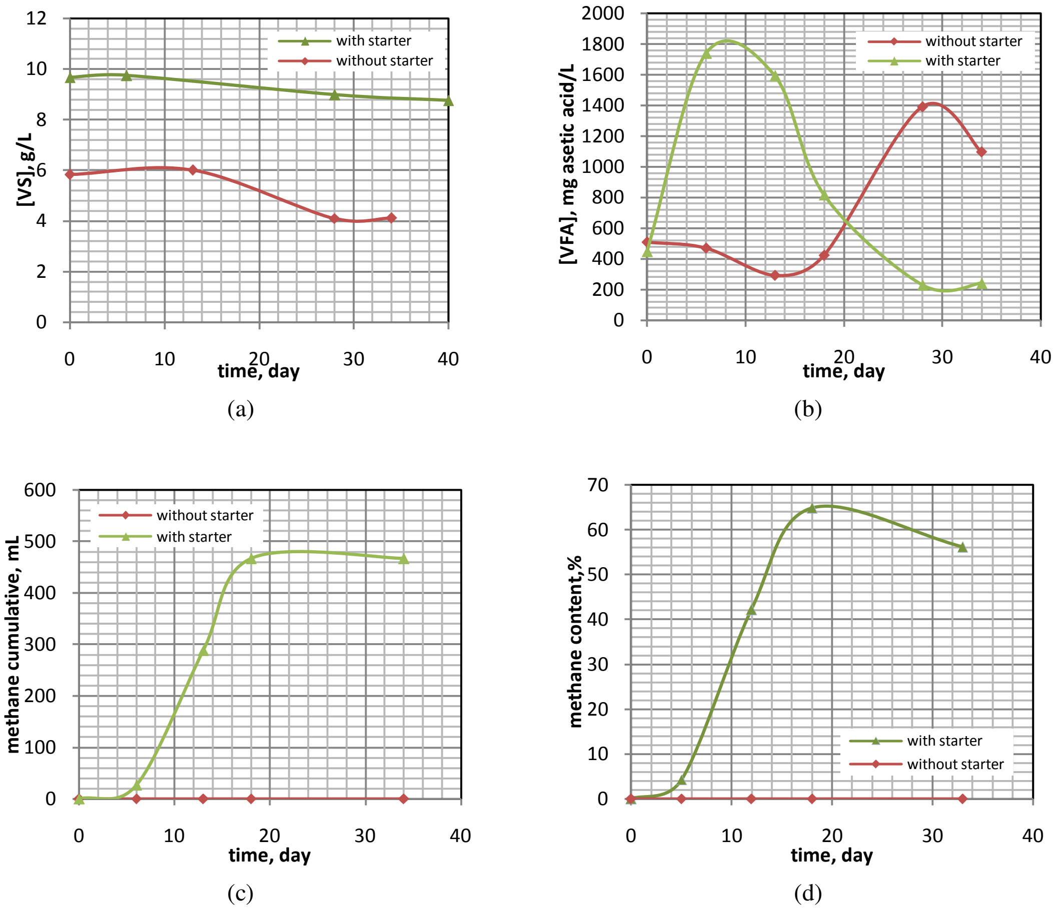

Figure 2. The correlation of process parameters and time.

hypothesis that there was no methanogenic bacteria in the soybean curd waste water caused by the low pH value and the opened soybean curd formation process.

B. The Potentiality for Power Generation

This section will study the power potentially can be generated from the biogas and estimate the soybean curd waste water that must be provided as anaerobic digestion substrate to generate a certain amount of power. The calculations are done using Equation (1), (2), (3), and (4).

Experiment result showed that approximately of 467.065 ml methane was produced from biogas digester fed with 400 gram soybean curd waste water. With the assumption that the Gen-Set efficiency is 50%, the energy that can be generated from the biogas will be 7,543.985 joule. To generate power as high as 0.7 kW and as long as 12 hours (8.4 kWh) per day, the energy that must be generated is 30,240,000 joule or it is needed approximately of 1,603.39658 liters soybean curd waste water per day to be fed in to the biogas digester. Due to the amount of waste water produced from this industry (soybean curd industry with capacity of 100 kg soybean per day will produce waste water approximately of 170-290 liters [17]), the capacity of the soybean curd industry must be as high as 697.13 kg soybean per day to generate the power. This calculation result show that the soybean curd waste water biogas electric power can be generated from the large scale soybean curd industry.

V. CONCLUSIONS

Analysis result show that acidogenic and methanogenic bacteria were existed in the active digester effluent and no methanogenic bacteria existed in the soybean curd waste water. The addition of active digester effluent will accelerated the degradation start-up time and direct the process to methane formation so that the final product obtained will be methane. The high methane content obtained (more than 64%) is much higher than if cow manure used as source of substrate as high as 53.0003%, so that this biogas very potential for power generation. The capacity of soybean curd industry must be as high as 697.13 kg soybean per day to generate the soybean curd waste water biogas electric energy of 8.4 kWh.

Further suggestion, the research to study the anaerobic co-digestion process of the waste water and the solid waste produced from soybean curd industry is needed to increase the yield of biogas and estimate the potentiality for biogas power generation in home and mid-scale soybean curd industry.

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